working paper
department
of economics

INSTALLED BASE AND COMPATIBILITY,
WITH IMPLICATIONS FOR PRODUCT PREANNOUNCEMENTS

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Number 385

August 1985
Revised

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** Department of Economics, M.I.T. Financial Support from the National Science Foundation (grant 1ST-8510162) is gratefully acknowledged.

1. Introduction

When compatibility is important, an installed base of durable goods or training may affect the likelihood and desirability of innovation.[1] In this paper we analyze the private and social incentives for the adoption of a new technology which is incompatible with the installed base.

In the presence of compatibility benefits, an individual or firm that switches to a new, superior technology obtains the full benefit of the improved standard only if other current users also switch and if new users adopt the new technology. Thus users face a coordination problem. Each user would be happy to switch if it knew that others would too, but it may be reluctant to switch on its own. There is thus the possibility of "excess inertia": a tendency not to switch to a superior new standard when important network externalities are present in the current one.

We have previously examined this possibility in a model in which payoffs depended only on who switched and not on when they switched (Farrell and Saloner (1985)). We found that symmetric excess inertia (a Pareto superior new technology not being adopted because of the coordination problem) could not occur with complete information.[2,3]

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[1]Benefits from compatibility arise, for example, when computer software can be used on different computers or where friends can exchange cassettes for their VCR's. There are also benefits when spare parts and servicing become easier to obtain because other consumers use the same product or technology. See Farrell and Saloner (1985) and Katz and Shapiro (1985) for other examples of the benefits from compatibility.

[2]The intuition for this result can be obtained by considering a sequence of N decision makers contemplating switching, and using a backwards induction

In many cases, however, payoffs arrive as a flow of benefits, with the flow to any user at any time depending on the total number of current users of the technology. Then one possible source of inertia when a new technology is introduced is the installed base of users of the old technology. The presence of this installed base yields a potentially large flow of network externalities to any new adopter of the old technology. By contrast, a user who adopts the new technology enjoys a relatively low flow of benefits until the new technology has attracted a large base of its own. Even if the new technology is a superior one, this difference in the initial flow of benefits may deter early adoption.[4] However, if everyone is deterred from early adoption the new technology may never get off the ground and users will remain with the status quo. We study this phenomenon and its implications in two related models.

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[2](cont'd) argument. If everyone else has switched, the Nth decision-maker will choose to switch. But then the (N-1)st decision-maker can be certain that it will be followed in a switch by the Nth decision maker if its predecessors have all switched. Thus it too will find it optimal to switch, and so on. See Farrell and Saloner (1985), Section 2.

[3]We also analyzed the problem with incomplete information. We found there that symmetric excess inertia could indeed arise. With incomplete information about the benefit of the network externalities to others, no firm can be sure that it would be followed in a switch to the new technology. This uncertainty can lead all the firms to remain with the status quo even when they do all in fact favor switching, because they are unwilling to risk switching without being followed.

[4]If the new technology is proprietary, its sponsor may be able to overcome this problem by "introductory" pricing. Except in our discussion of preannouncements and predation, however, we will assume that each technology is competitively supplied so that this cannot occur. (Arthur (1983) calls this "unsponsored" technology). For a discussion of the effects of sponsorship, see Katz and Shapiro (1985b). Unless otherwise specified, our payoff functions are net of competitive prices.

•A Model With Many Small Adopters

First we examine the case in which there are many users, each of which has only a small effect on the network externalities of the group. We suppose that there is a continual stream of new users over time. We examine what determines whether a new (and unexpected) technology gets adopted and emerges as the new standard.

At the time that the new technology becomes available there may already exist a substantial installed base of capacity using the old technology. For example, there was a large installed base of "Standard 8mm" movie cameras and projectors when "Super 8" was introduced; the "QWERTY" keyboard was ubiquitious by the time the existence of the Dvorak keyboard became widely known (see David (1985)); and the motor car was invented at a time when there was a substantial installed base of horse-drawn carriages and streetcars.

As we show in Section 2, the presence of the installed base causes a disparity between the social incentives for the adoption of the new technology and the private incentives facing individual decision-makers. This is so for two main reasons. First, the adoption of the new technology imposes a cost on the users of the old technology. Their network ceases to grow, and may even shrink as some current users abandon their old equipment for newer equipment that uses the new technology. For instance, recent purchasers of Standard 8 equipment at the time of the introduction of Super 8 suffered a loss (relative to the benefits they expected) that was not taken into account in the decisions of new adopters nor by the firms who introduced the new technology. The reduced availability of film and servicing and the delays in processing that have resulted from the decrease in the size of the network have made Standard-8 unattractive. Second, when the new technology first becomes available, potential adopters face the following choice: they

can adopt the new technology and enjoy small network benefits until the network is established (and possibly very large benefits thereafter), or they can adopt the existing technology and enjoy the benefits of the current installed base. These early adopters ignore the benefits they confer on later adopters of the new technology if they switch early. In our model it turns out that the outcome depends mainly on the size of the installed base at the time the new technology is introduced, how quickly the network benefits of the new technology are realized and the relative superiority of the new technology. The parameter space representing these attributes can be divided into three regions: In one the unique perfect Nash equilibrium is that the new technology is adopted, in another it is that it is not adopted and in the third region there are multiple equilibria.[5]

The existence of the regions in which there are unique equilibria enables us to illustrate unambiguously how inefficient technology choice can result from the two externalities discussed above.

Suppose for example that the new technology is far superior to the existing technology in the long run (i.e. once the network has a large base) but that it would take a long time for the network to become established. In that case the unique equilibrium may be that the new technology is not adopted. This occurs when the first potential users of the new technology are not prepared to bear the costs of waiting for the network to be formed. This is more likely to occur if the installed base is large or

[5]The multiple equilibria arise from the fact that the outcome may depend on new adopters' expectations about what other adopters will do. If each user expects everyone (no-one) else to adopt he will usually also adopt (not adopt). Imposing rationality on these expectations sometimes leads to a unique equilibrium, but not always. Where multiple equilibria exist, which equilibrium will in fact prevail may depend on which is more "focal" (see Schelling (1960) for a discussion of this). The incentive to make one outcome more "focal" than another may lead to large investments in introductory advertising and to "introductory" pricing.

if the network benefits are weak when there are small numbers of users of the new technology. Thus the installed base may be a significant source of excess inertia. The failure of the Dvorak keyboard may be an example of this. Once the first potential adopters decide not to adopt the new technology, of course, the excess inertia only becomes worse.

"Excess momentum" -the inefficient adoption of a new technology- can also arise. Suppose that the new technology offers the first potential user an advantage over the current technology. This first potential user of the new technology may be willing to adopt the new technology even though it will be a long time before the network is established. Once the first potential user has adopted the new technology it becomes even more attractive for later users to follow suit. If the new technology is sufficiently attractive to early adopters the unique equilibrium may be that the new technology is adopted. Excess momentum may result when the "stranding effect" (or "orphaning") on the users comprising the installed base is sufficiently important.

Because the size of the installed base may critically affect adoption, firms will seek strategic actions to affect it. One such action that has been the focus of antitrust litigation is the announcement of future availability of a new product.[6] In each case the defendant has been charged with making a "premature announcement" or a "predatory preannouncement" in order to discourage existing customers from switching to another supplier and to encourage those intending to buy soon to wait, and thus not become part of

[6]See Fisher, McGowan and Greenwood (1983) for a discussion of "predatory preannouncements" in the IBM case. Specific cases include California Computer Products Corp. v IBM Corp., 613F.2d 727 (9th Cir. 1979); Memorex Corp. v. IBM Corp, 636 F.2d 1188 (9th Cir. 1980), and Berkey Photo Co. v Eastman Kodak Co., 457F. Supp. 404 (S.D.N.Y. 1978), 603 F.2d 262 (2d Cir. 1979) and 444 U.S. 1093 (1980).

the "installed base". No formal models have been developed to deal with this question. However, several authors have rejected the contention that premature announcements can be anticompetitive. For example:

> "In general, there is no reason to inhibit the time when a firm announces or brings products to the marketplace. Customers will be the final arbiter of the products quality and the firm's reputation... Advance announcements of truthful information about products cannot be anticompetitive. Indeed, such announcement is procompetitive; competition thrives when information is good." (Fisher, McGowan and Greenwood (1983) p. 289).[7]

We show below, however, that, when there are significant network externalities, the timing of the announcement of a new incompatible product can critically determine whether the new product supercedes the existing technology or not. Furthermore, due to the externalities arising from the installed base, it is possible that a preannouncement will secure the success of a technology that is socially inferior to the existing technology, and that would not have been adopted absent the preannouncement.

The intuition for this result is the following: With a preannouncement there are two effects that favor the new technology. First, if some users decide to wait for the new technology, the network benefits when the new technology is introduced (and adopted by the users that have been waiting for it) will be larger than otherwise. Second, the installed base on the current technology will be reduced by the number of consumers who wait. We demonstrate the possibility of cases in which the unique equilibrium without a preannouncement is that the new technology is not adopted, while the unique

7 Similarly, Landis and Rolfe (1985) state: "...the welfare of consumers can only be increased by having additional correct information that is relevant to their purchasing decision."

equilibrium with a preannouncement is that it is adopted. Of course, here the potential users who decide to wait for the new technology are indeed well-informed "arbiters of the product quality" and their welfare is increased. However, they are not the only ones that matter. Their adoption of the new technology is a negative externality on the users in the installed base and on later adopters who may have preferred the old technology to the new. Thus, it is quite possible that the effect of the preannouncement is to reduce welfare in equilibrium.

•A Model With Two Large Adopters

In our second model, we examine the case where each of the users is large in the sense that each contributes significantly to the network benefits of the others. We suppose that each is currently a user of the existing technology, and consider their decision to switch to the new technology (which we suppose is indeed known to be superior to the old). For simplicity we study the two firm case. General Motors and Ford considering the adoption of a new automated technology might be an example. Each firm benefits in terms of cost savings if the other also adopts the new technology, since economies of scale in the production of the new technology, by third parties will be realized and there may also be spillovers in the benefits from learning about implementing the new technology. Another example would be the adoption of a new operating system for microcomputers by Apple and IBM. Here the network benefits arise through the compatibility of software if the same operating system is used.

Realistically, each firm's eagerness to switch will depend, inter alia, on the condition of its current equipment (does it need replacing anyway?),

how well its current product line is doing (does the firm want to change the products it is offering for other reasons?), whether it is planning the addition of new capacity, etc. Looking forward the firm will thus be uncertain about when it will be advantageous for it (and for its rival) to switch. We model this uncertainty about varying eagerness to switch over time by supposing that "opportunities to switch" for each firm arrive randomly over time. (In particular, we assume that these opportunities follow a Poisson arrival process). When such an opportunity presents itself, the firm's problem is the following: it can switch now or it can wait until its rival has an opportunity to switch, hope its rival switches at that opportunity, and then switch itself at <u>its</u> next opportunity.

The equilibria of this model can involve the firms' switching too reluctantly (excess inertia), too eagerly (excess momentum), or efficiently. The possible inefficiencies arise from two externalities in the model. First, when a firm switches it robs its rival of some network benefits for the period during which they are using incompatible technologies, and the switching firm ignores this in its calculations.[8] Second, when a firm switches it facilitates the move to the new technology from which the rival will later benefit; the firm also ignores this effect. The paper is

organized as follows: Section 2 presents the model with a continual stream of new users over time. Section 3 presents the model with two firms and a Poisson arrival process of switching opportunities.
Section 4 concludes the paper.

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[8]Indeed, this harm to the rival may provide an added incentive to switch if structural conditions are such that predation is possible.

2. A Model With Many Small Users

In this section we study a model in which a stream of potential users arrive over time. Calculations are considerably simplified by supposing that users are infinitesimal and arrive continuously over time with arrival rate $n(t)$. We assume that $n(t) > 0$ for all t (i.e. we do not study shrinking markets). We define $N(t) = \int_0^t n(t')dt'$. We suppose that before $t=T^*$ only technology U is available. At time T^* a new technology, V, becomes available. Until we discuss preannouncements, we shall assume that the new technology is unanticipated.

We denote the instantaneous value of having technology U when the size of the U-network is x (i.e. when the users of technology U have measure x) by $u(x)$. The presence of network externalities implies that $u'(x) > 0$. A useful concept is the net present value of benefits to a user who adopts the U-technology at time T, if all later users also adopt U. If users have a discount rate r, we can define this as

$$\bar{u}(T) \equiv \int_T^\infty u(N(t))e^{-r(t-T)}dt.^{9} \qquad (2.1)$$

An interesting example (and one that we will carry through this section) is the linear case:

$$n(t) = 1;\ N(t) = t$$

$$u(x) = a+bx \text{ (so } u(t) = a+bt).$$

Here "a" represents the "network-independent" benefits: the value to a user if there are no other users in the network. After a length of time t has

[9] Consumer surplus is thus $\bar{u}(T)$ minus the price of technology U at time T. If we assume that price is constant over time and across technologies then prices are common to most comparisons and can be ignored. While this is not realistic, it considerably simplifies notation and involves no loss of insight. The only comparison for which price is relevant is when the owner of a U-machine considers scrapping it to buy a V-machine. We assume that the price is high enough that this will not happen.

elapsed the network has grown to size bt, giving rise (in the linear case) to network-generated benefits of bt. For this case we have:

$$\bar{u}(T) = \int_T^\infty (a+bt)\, e^{-r(t-T)} dt$$

$$= \frac{a}{r} + b \int_0^\infty (\tau+T) e^{-r\tau} d\tau$$

$$= \frac{a+bT}{r} + \frac{b}{r^2} \,. \qquad (2.2)$$

This has an appealing interpretation. The user that adopts the technology at time T joins a network of size T, yielding an initial benefit flow a+bT. The NPV of benefits if the network size remains unchanged is (a+bT)/r which is the first term of the expression. As should be expected, this is increasing in a,b and T and decreasing in r. The second term, b/r^2, therefore gives the benefit to the adopter at time T from the <u>future</u> growth in the network.[10] This term is increasing in b, the rate of network growth.

We also define the NPV of benefits to a user who adopts the technology at time T and is the last user to adopt it. This is $\tilde{u}(N(T)) \equiv u(N(T)) \int_T^\infty e^{-r(t-T)} dt = u(N(T))/r$. In the linear case this is (a+bT)/r.

The situation is similar for the new technology, V except that by the time that it is introduced the size of the installed base on technology U is N(T*). Therefore, if all new adopters after time T* use the new technology (and no current users of the old technology switch), the benefit flow at time

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[10]Each unit of time the network grows by b. The NPV of benefits from this increase in the network size (evaluated at the time the growth occurs) is b/r. Thus the growth gives rise to a benefit stream of b/r per unit of time, which has a NPV of $(b/r)/r = b/r^2$. It is this component of $\bar{u}(T)$ that is in jeopardy from the introduction of new technology.

t from using technology v is v(N(t)-N(T*)) for t > T*. The analogous expression to (2.1) is

$$\bar{v}(T) = \int_T^{\infty} v(N(t)-N(T^*))e^{-r(t-T)}dt \text{ for } T > T^*. \quad (2.3)$$

In the linear case we suppose that

$$v(x) = c+dx = c+d(t-T^*).$$

Thus V can be superior to U in one of two ways: It can offer a higher <u>network-independent</u> benefit (c>a), or it can have higher <u>network-generated</u> benefits (d>b). In this linear case we have

$$\bar{v}(T) = \int_T^{\infty} [c+d(t-T^*)]\, e^{-r(t-T)}dt$$

$$= \frac{c+d(T-T^*)}{r} + \frac{d}{r^2} \text{ for } T > T^*. \quad (2.4)$$

The interpretation here is the same as for (2.2). Also $\tilde{v}(T)$ is given by the first term of $\bar{v}(T)$ as before.

<u>Nonadoption Equilibria</u>

Figure 1 provides an illustration of the linear case with d > b, a = 0 and c > 0. Notice that as the figure is drawn we have $\bar{v}(T^*) < \tilde{u}(T^*)$. This means that even if the user who arrives at time T* is certain that all later users are going to adopt technology V, he prefers to adopt technology U. The benefits from the installed base outweigh the benefits from the superiority of technology V. Therefore, users in an interval following T* will adopt technology U. But then later users will find it even more favorable to adopt technology U since the installed base is larger (or, put another way, the $\bar{v}(t)$ curve is shifted horizontally to the right and $\tilde{u}(T) - \bar{v}(T)$ is even larger for T > T* than it is at T*). Hence, later users will also adopt

technology U. Thus, the unique perfect Nash Equilibrium in this case is that the new technology fails to be adopted. The presence of the installed base is a <u>barrier to entry</u> of the new technology.[11] This argument does not rely on the linearity of the example. We have proved the following proposition:

<u>Proposition 2.1</u>: If $\bar{v}(T^*) < \tilde{u}(T^*)$ the unique perfect Nash Equilibrium is that the new technology is not adopted.

From a welfare point of view there are arguments for and against the adoption of the new technology. If the new technology is adopted, each user for whom $\bar{v}(T) > \bar{u}(T)$ gains $\bar{v}(T) - \bar{u}(T)$. However there are two groups of losers. First, early adopters lose $\bar{u}(T) - \bar{v}(T) > 0$ if they adopt the new technology. Second, users who are stuck with old installed base technology suffer a loss at the time that the new technology is adopted. Evaluated at T^* that loss is equal to $\bar{u}(T^*) - \tilde{u}(T^*)$ for each user in the installed base. This is the difference in the NPV of benefits to users of technology U resulting from the fact that the network on technology U ceases to grow after T^*. In the linear case that is equal to b/r^2 for each user, or a total of bT^*/r^2.

In the linear case the net present value of the net gain in welfare from the adoption of the new technology is:

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[11]The fact that there is a barrier to entry of the new <u>technology</u> doesn't imply that there is a barrier to entry of new <u>firms</u>. If access to the manufacture of the existing technology is unimpeded, technology U may be competitively supplied. If however the supplier(s) of technology U is protected by patents or possesses proprietary information necessary to the production of technology U, then the presence of the installed base will be a barrier to entry of new firms into the industry.

$$G \equiv \int_{T^*}^{\infty} [\bar{v}(t)-\bar{u}(t)]e^{-r(t-T^*)}dt - bT^*/r^2.$$

The first term represents the gain (loss) to users who arrive after T* while the second term is the loss to the installed base. Rewriting,

$$G = \int_{T^*}^{\infty} [\frac{c+d(t-T^*)}{r} + \frac{d}{r^2} - \frac{a+bt}{r} - \frac{b}{r^2}]e^{-r(t-T^*)}dt - \frac{bT^*}{r^2}$$

$$= \int_{0}^{\infty} (\frac{d\tau}{r} - \frac{b}{r}(\tau+T^*))e^{-r\tau}d\tau + \frac{d-b}{r^3} - \frac{bT^*}{r^2} + \frac{c-a}{r^2}$$

$$= \frac{2(d-b)}{r^3} - \frac{2bT^*}{r^2} + \frac{c-a}{r^2}$$

$$= [2(d-b)-2rbT^* + r(c-a)]/r^3. \tag{2.5}$$

Given the various countervailing welfare considerations it is somewhat surprising that, in the linear case, if the only advantage of the new technology is in the rate of growth of the network (i.e. d>b but a=c), then it is never the case that the unique perfect equilibrium involves nonadoption when adoption would be welfare enhancing!

Proposition 2.2: In the linear example if a=c and $\bar{v}(T^*)<\tilde{u}(T^*)$ then welfare is reduced if the new technology is adopted.

Proof: From (2.5) if a=c, G>0 iff (d-b) > rbT*. But, by assumption,

$\bar{v}(T^*) \equiv \frac{c}{r} + \frac{d}{r^2} < \frac{a}{r} + \frac{bT^*}{r} \equiv \tilde{u}(T^*)$. Thus if a=c then d<rbT* and so G<0.

Q.E.D.

Although this result is somewhat special in that it applies only to the linear case, it is also instructive and suggests that clearcut excess inertia (non-adoption being the unique equilibrium and inefficient) may be exceptional.[12,13,14] It is possible, however, to generate examples in which there is excess inertia. In order for nonadoption to be the unique equilibrium in the linear case it must be that $r(c-a) + d - rbT^* < 0$ and for welfare to be greater with adoption we require $2d - 2rbT^* - 2b + r(c-a) > 0$. An extreme case is presented in Figure 2. Here there are no network benefits to the existing technology so that $\bar{u} = \tilde{u}$. Furthermore, the first potential user of the new technology has only a slight preference for the old technology ($\bar{v}(T^*) < \tilde{u}(T^*)$).[15] However this slight preference results in his choosing to adopt the old technology. All later users face the same choice and make the same decision. Thus, the new technology is not adopted although it would clearly be welfare enhancing.

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[12]The intuition for this result is the following. For it to be certain that the innovation will fail it must be the case that $\bar{v}(T^*) < \underset{\sim}{u}(T^*)$, i.e., $rbT^* > d + r(c-a)$. This means that d cannot be too large. This can be seen by referring to Figure 1: as d grows so does $\bar{v}(T^*)$, eventually leaving the range where nonadoption is the unique equilibrium. However if d is small, the advantage of the new technology over the old is reaped only in the distant future, where discounting renders it less valuable. Of course a higher value of d is possible (while still maintaining the inequality $\bar{v}(T^*) < \underset{\sim}{u}(T^*)$) if either r or T^* is large. However if T^* is large the loss to the installed base is also large, while if r is large the benefits from the new technology (which are reaped only in the future) are also correspondingly less valuable.

[13]Note that this result only rules out the possibility that inefficient nonadoption is the unique equilibrium. We show below that there are parameter values for which there are multiple equilibria, one of which is nonadoption. In that region it is also more likely that adoption will be welfare-enhancing. If nonadoption is somehow "focal" then excess inertia may be more prevalent here. Nonadoption is especially focal if there are several possible new technologies.

[14]We reach a similar conclusion in a static model in which users have different preferences over U and V. (See Farrell and Saloner (1985b)).

[15]This requires $r(a-c) > d$, i.e. a relatively large advantage in the user-specific benefits of the old over the new technology.

Recall from (2.5) that in the linear example

$G = [2(d-b)-2rbT^* + r(c-a)]/r^3$. Thus, $\frac{dG}{dT^*} < 0$, $\frac{dG}{dd} > 0$, $\frac{dG}{db} < 0$ and $\frac{dG}{d(c-a)} > 0$. Also $\frac{dG}{dr} > 0$ iff $r > 6(d-b)/[4bT^*-2(c-a)]$. Thus the innovation is more likely to be welfare enhancing (if it is adopted) the earlier it is introduced, the faster the network benefits to the new technology grow, the more slowly the network benefits to the old technology grow, and the larger the network-independent advantages of the new technology are. The effect of r on G depends on the magnitude of r. If r is small and the relative growth rate of network benefits from the new technology is high (d>>b) or the network-independent benefit is very high (c>>a), then the new technology is superior since the substantial future benefits are worth waiting for. In that case, increasing r slightly and thus diminishing the value of the future benefits makes the welfare gain smaller. On the other hand, if r is large, a is close to c, and b is close to d so that the current system is superior, G is negative. Increasing r then merely drives G closer to zero and thus decreases the welfare loss.

Adoption Equilibrium

There are two cases where the unique perfect Nash equilibrium is that the new technology is adopted. The first is where $\tilde{v}(T^*) > \bar{u}(T^*)$. (In the linear case this requires $c > a+bT^*$ i.e. substantial network-independent benefits to the new technology). In this case the first user who is considering adopting the new technology prefers to be the only adopter of the new technology rather than adopting the old technology along with everyone else. It is thus a dominant strategy for the first user to adopt the new technology. But then the next user finds the new technology even more

attractive, etc.

"Excess momentum" can arise here. For example, consider the linear case and suppose that $c \equiv [a+bT^* + \frac{b}{r} + r\varepsilon]$ and $d=0$. In that case $\bar{v}(t) = \tilde{v}(t) = \frac{c}{r}$, $\bar{u}(T^*) = \frac{a+bT^*}{r} + \frac{b}{r^2}$ and $\tilde{v}(T^*) - \bar{u}(T^*) = \varepsilon$. Thus for any $\varepsilon > 0$ the unique perfect equilibrium is that the new technology is adopted. The situation is illustrated in Figure 3. The (undiscounted) gain to adopters from adoption of the new technology is the shaded triangle (the discounted gain is even smaller). The loss to the installed base from the adoption is the shaded rectangle. There is also a loss to later adopters (dotted region). Since the shaded triangle can be made arbitrarily small (by shrinking ε) there obviously can be excess momentum. Indeed it is possible that the losses are quite large and the gains minuscule, and yet the new technology is adopted!

Another situation in which, aside from a technicality, it is the unique perfect Nash equilibrium for the new technology to be adopted is the following. Suppose that $\bar{v}(t) > \bar{u}(t)$ for all t, $\tilde{v}(t) > \bar{u}(t)$ for all t greater than some T', and $\bar{u}(t) < \bar{u}_{max} < \infty$ for all t and some $\bar{u}_{max}$. This is illustrated in Figure 4. Here, if all users between T^* and T' adopt the new technology it is then a <u>dominant</u> strategy for all later users to adopt it as well (since $\tilde{v}(t) > \bar{u}_{max}$). Knowing this, it is also a dominant strategy for the potential adopter who arrives "just before" T' to adopt the new technology if all preceding users have adopted it. But then it is optimal for the potential adopter who arrives just before him to adopt it as well. Using backwards induction from T' it would seem that the unique equilibrium is that the new technology be adopted.[16] The flaw in this

[16]This is a modified version of Proposition 1 of Farrell and Saloner (1985).

argument is that, with a continuum of potential users, there is no potential user "just before" T'.[17]

The above argument does apply, however, when there is a sequence of discrete arrivals. If everyone preceding a particular agent has adopted the new technology, then if he adopts it as well he ensures the adoption by all subsequent users. This in turn confers some power on the immediately preceding potential adopter and all those preceding him. Note that this is true no matter how frequently adopters arrive, as long as the arrival times remain discrete. Thus, if the conditions of the previous paragraph are satisfied <u>and</u> users arrive at discrete intervals, adoption will indeed be the unique equilibrium.

The above results can be summarized as follows:

<u>Proposition 2.3</u>: It is the unique perfect Nash equilibrium that the new technology is adopted if

(i) $\tilde{v}(T^*) > \bar{u}(T^*)$, or

(ii) $\bar{v}(t) > \bar{u}(t)$ for all t, there exists a T' and $\bar{u}_{max}$ such that $\tilde{v}(t) > \bar{u}_{max}$ for all $t > T'$, and users arrive at discrete intervals.

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[17]While adoption is <u>an</u> equilibrium in the case of a continuum of users, nonadoption is as well. In the discrete case, the potential user just before T' is able to exert a large amount of influence. To see this suppose that each user believes that no-one will adopt the new technology. In that case he won't want to adopt it either. Thus, no-one will adopt it. Furthermore, a deviation (to adoption) by any single user won't change any other user's calculations since the deviating user has measure zero and thus no effect on N(T) and hence on any of the payoffs.

Multiple Equilibria

In those cases not covered by Propositions 2.1 and 2.3 there is both an adoption and a nonadoption equilibrium. Suppose that $\bar{u}(T^*) > \tilde{v}(T^*)$ and $\bar{v}(T^*) > \tilde{u}(T^*)$. Then the potential user that arrives at T* would rather adopt the old technology if he was sure that all later users were also going to adopt it ($\bar{u}(T^*) > \tilde{v}(T^*)$), but he would rather adopt the new technology if he was sure that all later users were going to adopt <u>it</u> ($\bar{v}(T^*) > \tilde{u}(T^*)$). Under these circumstances, if everyone expects adoption to occur it will occur; but if no-one expects it to occur then it won't.

Implications for Anticompetitive Behavior

(a) Product Preannouncements

In the preceding analysis we have assumed that the new technology becomes available unexpectedly. However, if potential users foresee that the new technology will become available, they may wait for the new technology in preference to adopting the old one immediately. But then the new technology's installed base will start off much larger than otherwise. It is then possible that a technology will be adopted with such a "product preannouncement" that would not have been adopted otherwise. Without the preannouncement the old technology may develop an unstoppable momentum whereas the preannouncement can stop this "bandwagon effect" before it starts.

We provide conditions below under which the preannouncement means the difference between adoption and nonadoption: the unique equilibrium with no preannouncement is that the technology is not adopted, but with the

preannouncement the unique equilibrium is that it is adopted. We also show by means of an example that the preannouncement can be welfare reducing.

Suppose that a preannouncement is made at $T^*-\tau$ for a product that will become available at T^*. Suppose further that $n(t)$ is constant. Then if all potential users in the interval $[T^*-\tau, T^*]$ wait until time T^* and then adopt the new technology, and all later users also adopt the new technology, the NPV of adopting the new technology at $t > T^*$ is $\bar{v}(t+\tau)$, i.e. it is the value it would have been at $T^*+\tau$ with adoption but without the preannouncement. We can show:

<u>Proposition 2.4</u> If (i) $\bar{v}(T^*) < \tilde{u}(T^*)$ and (ii) $\tilde{v}(T^*+\tau-t')e^{-rt'} > \bar{u}(T^*-t')$ for all $t' \in [o, \tau]$ then

(a) without the preannouncement the unique equilibrium is that the new technology is not adopted, and

(b) with the preannouncement the unique equilibrium is that the new technology is adopted.

These assumptions are illustrated in Figure 5. When all the potential users between the time of the preannouncement ($T^*-\tau$) and the date the product becomes available (T^*) wait until T^* and then adopt the new technology, the $\bar{v}$ and $\tilde{v}$ curves are "shifted to the left" by τ. The outlook for a potential user at T^*+t absent the preannouncement is the same as the outlook of a potential user at $T^*+\tau+t$ with the preannouncement.

<u>Proof of Proposition 2.4</u>: Assumption (i) implies (a) by Proposition 2.1. From (ii) $\tilde{v}(T^*+\tau)>\bar{u}(T^*)$. But then if all the potential adopters that arrive between $T^*-\tau$ and T^* wait to adopt the new technology at T^*, then by

Proposition 2.3 (i), at T^* the unique equilibrium is that the new technology is adopted. Then Assumption (ii) ensures that each potential adopter that arrives between $T^*-\tau$ and T^* would rather wait until T^* and adopt the new technology at T^* (if everyone that arrived since $T^*-\tau$ also did and everyone else who arrives later also does) than to adopt the old technology, even if everyone else also adopts the old technology. But then the argument of Proposition 2.3 (or Proposition 1 of Farrell and Saloner (1985)) implies (b).[18]

Proposition 2.5: The preannouncement may be welfare reducing, even though the conditions of Proposition 2.4 hold.

Proof: We construct an example as follows: First, assume that u is as in the linear example and set $b < r$. Let $\tau \equiv \inf\{t': \bar{u}(T^*-t') < \tilde{u}(T^*)-\varepsilon\}$ for some (arbitrarily small) ε. Second, let

$$v(x) = \begin{cases} 0 \text{ if } x < \tau \\ c' \text{ if } x > \tau. \end{cases}$$

The new technology is valueless if the network size is less than τ and generates a benefit flow c' otherwise. Now set c' so that $(c'/r)e^{-r\tau} > \bar{u}(T^*-\tau)$. Then $(c'/r)e^{-rt'} > \bar{u}(T^*-t')$ for all $t' < \tau$. Thus the conditions of Proposition 2.4 are satisfied. Notice that because of the linearity of u this construction can be carried out for any T^*. It can easily be checked that the welfare increase (evaluated at T^*) to adopters of the new technology is bounded above and is independent of T^*. However, the loss in welfare to the installed base is $T^*[\bar{u}(T^*-\tau)-\tilde{u}(T^*-\tau)] = T^*b/r^2$ which can be made arbitrarily large by increasing T^*. Q.E.D.

[18] This argument also assumes a discrete arrival of potential users between $T^*-\tau$ and T^*.

We have argued that a preannouncement may be welfare reducing. Dominant firms have often faced antitrust charges of "anticompetitive" product preannouncements. See footnote 6 above. In our analysis above we have made pricing exogenous, and so our model is several steps away from showing that the welfare-reducing preannouncements are also anticompetitive. However, it is a simple matter to take these last steps. Suppose that the old technology is provided competitively and that the u function takes into account the pricing that results from that competition. Suppose further that the new technology is provided by a monopolist and that the v function represents the benefit to consumers when the monopolist prices so as to maximize profits assuming that his proprietary V-technology will be adopted. Under the assumptions of the example, absent a preannouncement the monopolist's product will fail to be adopted. Of course the monopolist might be able to induce adoption by offering a discount until the technology has become adopted. However, the preannouncement is a costless way of achieving the same result. The net effect is to destroy the competition and (as we have seen) perhaps to reduce welfare as well.

The preannouncement is likely to be most effective where the current technology could achieve widespread adoption in a short time between announcement time and introduction. Then the preemptive effect of the preannouncement will be crucial. So, especially when targeted against a fledgeling technology, the preannouncement may well be anticompetitive.

(b) Predatory Pricing

The above analysis examined the possiblity of anticompetitive behavior by a firm introducing the new technology. Where the current technology is

provided by a monopolist there is the possibility of anticompetitive behavior by the incumbent. In particular, predatory pricing is often a rational response to entry.

Suppose that when the incumbent sets its profit-maximizing prices over time (assuming no new technology) the flow of net benefits to users is given by the u function. Suppose further that the new technology will be competitively supplied and that the v function represents the benefits net of the competitive price. Finally, suppose that u and v are as given in Figure 6.

Since $\tilde{v}(T^*) > \bar{u}(T^*)$ the unique equilibrium, absent strategic pricing, is that the new technology is adopted. But the incumbent can induce the user that arrives at T* to stay with the current technology by reducing the price of the current technology to him by (just over) $\bar{v}(T^*) - \tilde{u}(T^*)$. Then that user would prefer being the last user on the current technology to being the first user of the new technology, even if all later users adopt the new technology. If the incumbent provides such an inducement to all the users who arrive between T* and T', it will then become impossible for the new technology to enter (since $\bar{v}(T') < \tilde{u}(T')$). The (undiscounted) cost to the incumbent of this strategy is given by the shaded area. Depending on the parameters of the model this may well be profitable. It may also involve a shortrun sacrifice of profits.

The private costs of carrying out the predatory policy are not the same as the social ones. The cost to the monopolist of carrying out the predation occurs through price reductions which are merely transfers to users. The relevant social costs are the costs to users who arrive after T* from the fact that the new technology is not adopted. The relevant social benefit is

that the predatory pricing protects the installed base against "stranding". Thus the welfare effects of the predation are ambiguous.

Since the sole purpose of the incumbent's pricing policy is to drive its rivals out of the industry and since it may involve a short run sacrifice of profits, this is a classic case of predatory pricing. Notice that in this model the monopolist can raise its price once the rivals have left the industry, without inducing re-entry, even if there are no entry or exit costs. This is because if the incumbent fights off entry until T' it thereafter has a barrier to entry because of its (then) insurmountable advantage of installed base.

It is interesting to apply to this case two leading rules that have been proposed for diagnosing predatory pricing. The Areeda-Turner (1975) test (under which predation is deemed to have occurred if the firm prices below average variable cost) can yield a false negative: provided the network benefits of installed base are sufficient, our example of predation does not require pricing below the incumbent's, or the entrants', average variable cost.

The test proposed by Ordover and Willig (1981) asks whether the firm's action would have been optimal if the entrant faced no re-entry costs. If so, then the action is deemed not to have been predatory. Re-entry costs are defined as "the cost that a firm that has exited a market must incur to resume production." Here, however, "re-entry costs" are not the point. The

opportunity to supplant the monopolist is only available until time T'. This evanescence of opportunity is assumed away in the Ordover-Willig test. Thus this test may also yield a false negative. What the test misses is the following: the delay that the incumbent wins through its predatory action, changes the "condition of entry". As time passes the barriers to entry rise as the incumbent becomes more entrenched. In this setting this is due to the benefits from compatibility; more generally, the same will be true where brand recognition or a product's reputation are important in determining consumer choice behavior. Learning by doing will have a similar effect.

Thus we see that, on the one hand, predation of this sort may be missed by standard tests. On the other hand, if the "stranding" externality is important enough, the predation may be welfare-enhancing.

3. A Model with Two Large Adopters

3.1 The Model

Two agents, 1 and 2, are initially using a pre-established standard or technology U. We normalize their net payoff flows at zero for each. Another technology, V, is available; however, each agent has only occasional chances to switch. To be precise, each agent encounters switching opportunities randomly in a Poisson process with rate $\lambda > 0$.

An agent with a chance to switch faces the following choice. If he switches, then he knows that the other agent will not immediately be able to switch, so that they will be incompatible for a while. If he does not switch, then the other may or may not choose to switch at his next opportunity. We will consider agents' private incentives to switch or not to switch, and the nature of the externalities involved.

We write u(k) for each agent's flow of net payoff if he is on standard U alone (k=1) or together with the other agent (k=2). Likewise, we define v(k). Notice that this assumes that the firms' payoffs are symmetric.

As above, we interpret the two "agents" as <u>users</u> of the technology. If one of them switches, they become incompatible (because the other cannot immediately switch). In this interpretation, "installed base" is the non-switcher.[19] It is natural to assume that network externalities are positive:

$$u(1) < u(2) \tag{3.1}$$

$$v(1) < v(2). \tag{3.2}$$

For notational convenience, we normalize u(2) at 0.

3.2 Efficiency

It should be clear that the efficient rule is either (a) never switch, or (b) switch as soon as possible. Which of these is better?

To answer that question, we suppose that agent 1 has a switching opportunity at a time we call t=0. Let $\tilde{t}$ be the (random) next switching opportunity for agent 2. Then the social value of switching is

$$\int_0^{\tilde{t}} [v(1) + u(1)]\, e^{-rt} dt + \int_{\tilde{t}}^{\infty} 2v(2)e^{-rt}\, dt$$

[19]In a second interpretation, our two agents are competing <u>suppliers</u> of a durable good embodying technology U or V. Buyers are concerned with network externalities: in particular, with compatibility with the installed base of equipment. If this network effect is strong enough, it may be the case that

$$u(1) > u(2) \tag{3.3}$$

Also, if the installed-base effect is <u>not</u> so strong, so that buyers begin to buy the new technology as soon as it is available, there may be a <u>first-mover advantage</u>:

$$v(1) > v(2) \tag{3.4}$$

Both (3.3) and (3.4) are influenced by buyers' expectations of whether the new technology will succeed, and by the relative sizes of the two suppliers.

$$= [v(1) + u(1)] \frac{1-e^{-r\tilde{t}}}{r} + 2v(2) \frac{e^{-r\tilde{t}}}{r} . \tag{3.5}$$

It is well-known that

$$E(e^{-r\tilde{t}}) = \frac{\lambda}{r+\lambda} . \tag{3.6}$$

Thus the expected social value of switching is

$$\frac{v(1) + u(1)}{r+\lambda} + \frac{2v(2)(\lambda/r)}{r+\lambda} . \tag{3.7}$$

In other words, we get

Proposition 3.1: Switching is socially efficient if and only if

$$v(1) + u(1) + \lambda \frac{2v(2)}{r} > 0 \tag{3.8}$$

Equation (3.8) has a straightforward interpretation. Suppose a firm switches. The cost of that switch (in the next instant) is $v(1) + u(1) - 2u(2)$, or $v(1) + u(1)$. The benefit of the switch (in the next instant) is the NPV of benefits from a combined switch to the new technology, or $2v(2)/r$, multiplied by the probability of achieving it, λ. The qualitative properties of (3.8) are not surprising. For example, if $v(2) < 0$ then by assumption also $u(1) < 0$ and $v(1) < 0$ so that switching is not efficient. If $v(2) > 0$ then switching is more desirable as λ increases (less time is spent incompatibly in transition) or as r decreases (transition effects are less important). Henceforth, we will assume $v(2) > u(1)$ unless we specify otherwise.

3.3 Equilibrium

As in Section 2 our chief concern is to investigate whether excess inertia or excess momentum can arise and, if so, for what parameter values these inefficiencies are most severe. Since excess inertia and excess

momentum arise in nonadoption and adoption equilibria, we analyze these in turn.

Nonadoption Equilibrium

We begin with a lemma.

Lemma: If both the following inequalities hold:

$$(\lambda+r)v(1) + \lambda[v(2) - u(1)] < 0 \tag{3.9}$$

$$rv(1) + \lambda v(2) < 0 \tag{3.10}$$

then neither agent will switch first, whatever his beliefs about whether and when the other agent might switch first.

Proof: The expected (private) payoff to switching, discounted back to the switching opportunity, can be calculated using the method of (3.5) - (3.7) since our assumption $v(2) > u(1)$ guarantees that a switch will be followed as soon as possible. The payoff to switching is

$$(r+\lambda)^{-1}(v(1) + (\lambda/r)v(2)) \tag{3.11}$$

To calculate the expected payoff to the alternative strategy (wait for the other to switch, then switch), we suppose that our agent (1) regards the time at which 2 will switch (if 1 does not switch first) as a random variable $\tilde{s}$. We write $\tilde{s} = \infty$ if 2 never switches first. If 1 does not switch first, then he gets a flow $u(2) \equiv 0$ until the random time $\tilde{s}$, at which point his present discounted value becomes

$$E\{\int_0^{\tilde{t}} u(1)\, e^{-rt}dt + \int_{\tilde{t}}^{\infty} v(2)\, e^{-rt}dt\}$$

$$= (r+\lambda)^{-1}(u(1) + (\lambda/r)\, v(2)) \tag{3.12}$$

where $\tilde{t}$ is the (random) elapsed time after $\tilde{s}$ before 1 has his next switching opportunity. Thus, at time 0, the expected present value of the "wait" strategy is

$$E[e^{-r\tilde{s}}]\ (r+\lambda)^{-1}(u(1) + (\lambda/r)\ v(2)) \tag{3.13}$$

Finally, we note that $\tilde{s}$ cannot occur before 2's first switching opportunity, so that, by (3.6),

$$0 < E[e^{-r\tilde{s}}] < \frac{\lambda}{r+\lambda} \tag{3.14}$$

Using (3.14) and comparing (3.11) and (3.12), we see that (3.9) and (3.10) are jointly a necessary and sufficient condition for waiting to be a dominant strategy. Q.E.D.

As an immediate consequence, we get:

<u>Proposition 3.2</u>: If (i) $(\lambda+r)\ v(1) + \lambda\ [v(2) - u(1)] < 0$ and (ii) $rv(1) + \lambda v(2) < 0$, then nonadoption is the unique equilibrium.

Note that if (i) holds, $u(1) > v(1)$ is a sufficient condition for (ii).

Recall that adoption is efficient if $[v(1) + u(1)]r + 2\lambda v(2) > 0$. It is easy to show that this condition together with (i) and (ii) can be simultaneously satisfied.[20] Thus there may be excess inertia.

Excess inertia is most likely when $v(1)$ is very negative and $u(1)$ is only moderately negative.[21] In that case each agent would rather that it was the other that initiated the switch and, moreover, it is so costly to switch alone that the firm would rather not switch at all than switch first.[22] The

[20] For example, set $v(2) = 2$, $v(1) = -30$, $u(1) = -1$, $r = 1/10$ and $\lambda=1$.

[21] Or, in our alternative interpretation, if $v(1) < 0 < u(1)$.

[22] If we allowed for incomplete information, we could find that "switching first" had the same role as "giving in" in bargaining models. Each might prefer to switch first, but prefer still more that the other do so. See e.g. Cramton (1984).

inefficiency arises, as in the previous section, because of the externality on the other agent. Each agent takes into account only its own share $v(2)$ of the benefits from a combined switch, rather than the total benefits $2v(2)$.

Adoption Equilibrium

In analogy with Proposition 3.2 we find:

Proposition 3.3: If (i) $(\lambda+r)\,v(1) + \lambda\,[v(2) - u(1)] > 0$ and (ii) $rv(1) + \lambda v(2) > 0$ then adoption is the unique equilibrium.

Proposition 3.3 follows from the proof of our lemma. Conditions (i) and (ii) together imply that each agent will wish to switch first whatever his beliefs about the other's willingness to switch first.

Is this equilibrium efficient? Recall that switching is efficient if $[v(1) + u(1)]r + 2\lambda v(2) > 0$. Suppose that $v(1) > 0 > u(1)$. Then if switching is efficient it is also an equilibrium. However it is also possible that switching is inefficient and yet it is the unique equilibrium, if $|u(1)| \gg |v(1)|$. The intuition behind this excess momentum is straightforward. It occurs when the first firm to switch benefits from the switch in the short-run (until the other also switches) and in the long-run. The rival, however, suffers greatly until it is also able to switch. This latter loss is an externality that the switching firm imposes on its rival and that it ignores in its switching decision.

If the loss that the second firm to switch suffers is large enough it is possible that a firm will seize its first switching opportunity even if switching is undesirable. In particular, suppose that firm 1 would not switch at t=0 if it thought its rival would never switch, i.e. that

$rv(1) + \lambda v(2) < 0$, but that it <u>would</u> switch if it thought its rival would switch at t, i.e. $(\lambda+r)\, v(1) + \lambda[v(2) - u(1)] > 0$. If these conditions hold (which requires $0 > v(1) > u(1)$) then immediate adoption is an equilibrium, even if $v(2) < 0$. This is a "preemption" equilibrium in which each firm believes its rival will switch when the opportunity arises and so switches itself at its first opportunity in order not to be the firm left "holding the old technology". This is, of course, not the only equilibrium with these parameter values. If both firms believed the other would never switch then neither would switch. Thus nonadoption is also an equilibrium.[23]

[23]If switching opportunities are observable, we can argue against the pre-emption equilibrium as follows. If 2 expects 1 to switch first, but observes him refraining from doing so, we might expect him to infer that 1 will not switch first, rather than inferring that 1 will <u>now</u> switch as soon as possible. If 1 believes that 2 would update as we suggest, then he can stop 2 from switching by refraining himself. Thus, for pre-emption to be a perfect equilibrium, updating after an unexpected failure to switch must take the form "I'm surprised you didn't switch; but I still expect you to switch at your next chance."

4. Conclusions and Possible Extensions

There can be excess inertia, even with complete information, when we allow for benefit flows over time in the presence of an installed base. There are two externalities in a switching decision: the stranding effect on the installed base, and an effect on the options available to later adopters. Since our previous model (Farrell and Saloner (1985)) is essentially "timeless", the installed base externality is absent. In that setting identical adopters always reach the efficient outcome. In the present paper installed base users are somewhat committed to the old technology, which is a source of bias against the new (perhaps superior) technology.

The biases we identify can be turned to anticompetitive uses. We analyzed two: anticompetitive product preannouncements, and predatory pricing. First, product preannouncements may prevent a bandwagon from gaining momentum. Secondly, an incumbent firm may be able to deter entry by a credible threat of temporary price reductions following entry. This is so even when there are no re-entry costs.

There are a number of ways in which the models could be generalized and extended. First, consider the model with small users. There we assumed that users live forever and products do not depreciate. Realistically, an installed base, once stranded, will shrink. The welfare cost of excess momentum will then be lower than in our model. Also, adoption is more likely, but if excess inertia does occur it is more costly.

We have not examined the effect of a changing pattern of the arrival rate of new users over time. We would expect, however, that if there is an unusual upturn in demand, perhaps because of a baby boom or an economic recovery, an innovation could gain a substantial network relatively quickly.

Innovations may therefore be concentrated in such periods. (See Shleifer (1985) for a model of endogenous business cycles based on this kind of effect). Similarly, the destruction of installed base by war may clear the decks for innovation.

Second, consider the model with large users. The most interesting extensions would make the users asymmetric, either in the frequency with which they consider switching or in the value they attach to compatibility. Large firms plausibly care less about compatibility with small rivals then *vice versa*. We therefore expect them to be *de facto* standard setters. Likewise, an agent who only rarely has a chance to switch may find his more flexible rival waiting for him to do so.

Another line of inquiry would consider multiple users. With equal sized users the first switcher sacrifices more in network benefits if there are many users. His strategic bandwagon power is also likely to be less. One might expect therefore, that excess inertia will be a more serious problem in this case. However, although it will take longer for the whole industry to switch, the first switching opportunities arrive more frequently. Thus the result is not obvious.

We believe that these are fruitful avenues for further investigation.

REFERENCES

Areeda, P. and D.F. Turner, "Predatory Pricing and Related Practices Under Section 2 of the Sherman Act, "Harvard Law Review, 88 (1975), 697-733.

Arthur, W.B., "On Competing Technologies and Historical Small Events: The Dynamics of Choice under Increasing Returns," mimeo, Stanford University, 1983.

Cramton, P.C., "Bargaining with Incomplete Information: An Infinite Horizon Model with Two-Sided Uncertainty," Review of Economic Studies, 167 (October 1984), 579-594.

David, P.A., "Clio and the Economics of QWERTY," American Economic Review, 75 (May 1985), 332-337.

Farrell, J. and G. Saloner, "Standardization, Compatibility, and Innovation", Rand Journal of Economics, 16(Spring 1985), 70-83.

Farrell, J. and G. Saloner "Standardization and Variety", M.I.T., mimeo, June 1985b.

Fisher, F.M., J. McGowan and J. Greenwood, Folded, Spindled and Mutilated: Economic Analysis and US vs IBM, MIT Press, 1983.

Katz, M. and C. Shapiro, "Network Externalities, Competition and Compatibility," American Economic Review, 75(July 1985), 424-440.

Katz, M., and C. Shapiro, "Technology Adoption in the Presence of Network Externalities," Discussion paper #96, Woodrow Wilson School, Princeton, July 1985b.

Landis, R., and R. Rolfe, "Market Conduct Under Section 2 - When is it Anticompetitive," in F.M. Fisher, ed., Antitrust and Regulation; Essays in Memory of John J. McGowan, MIT Press, 1985.

Ordover, J.A. and R.D. Willig, "An Economic Definition of Predation: Pricing and Product Innovation," Yale Law Journal, 91(1981), 8-53.

Schelling, T.C., The Strategy of Conflict, Cambridge: Harvard, 1960.

Shleifer, A., "Implementation Cycles," M.I.T., mimeo, 1985.

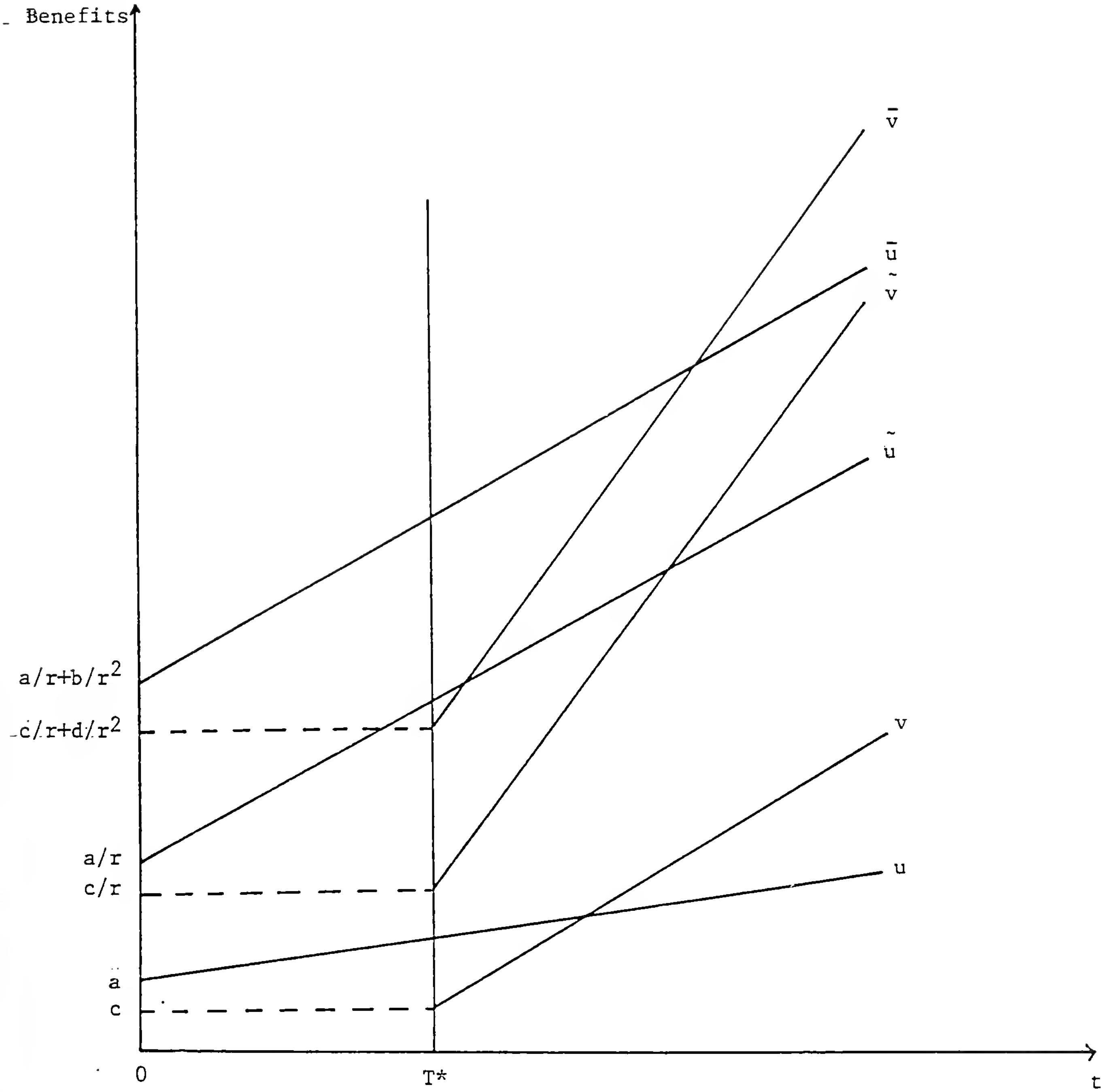

Figure 1: The Linear Example

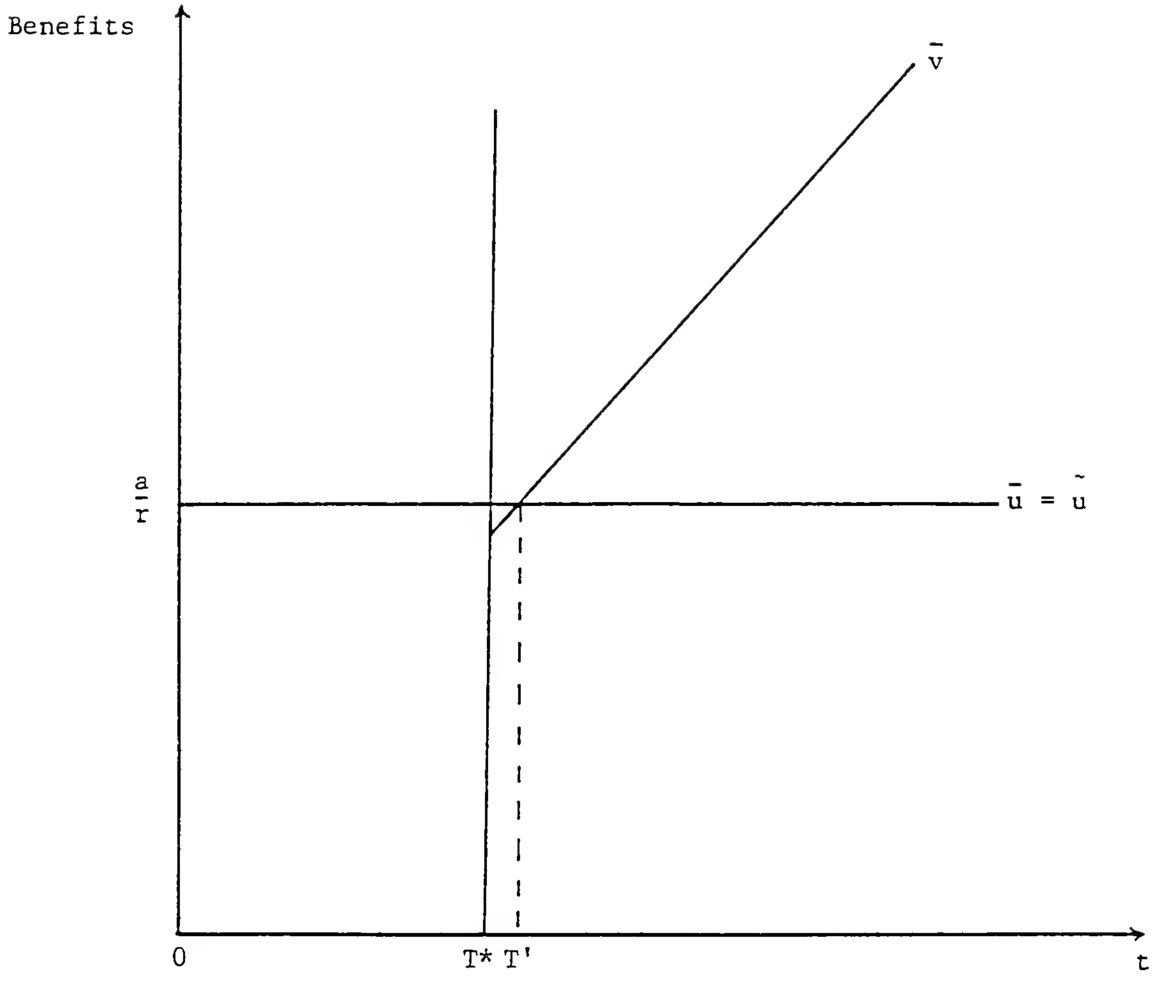

Figure 2: An Example of Excess Inertia

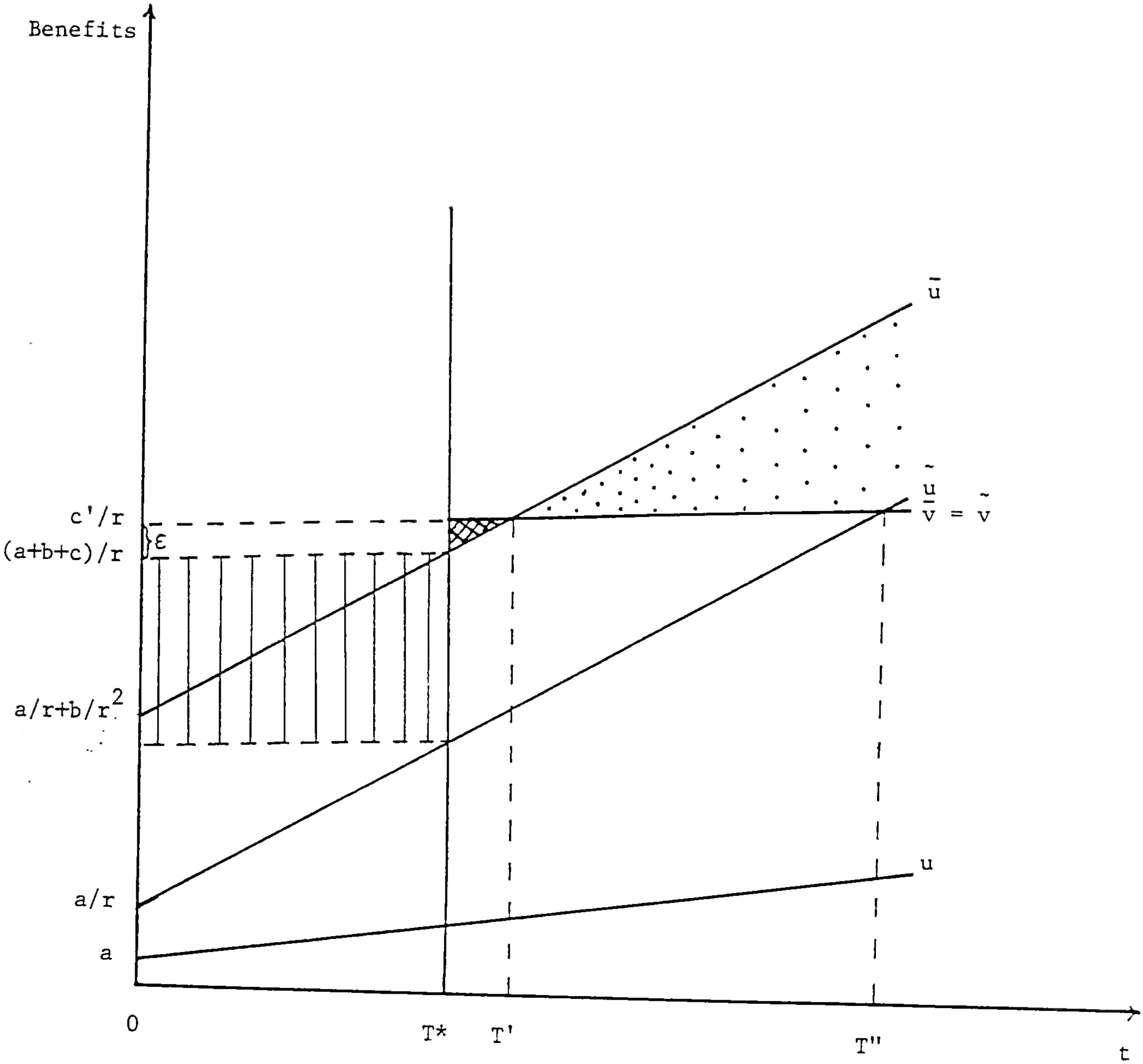

Figure 3: An Example of Excess Momentum

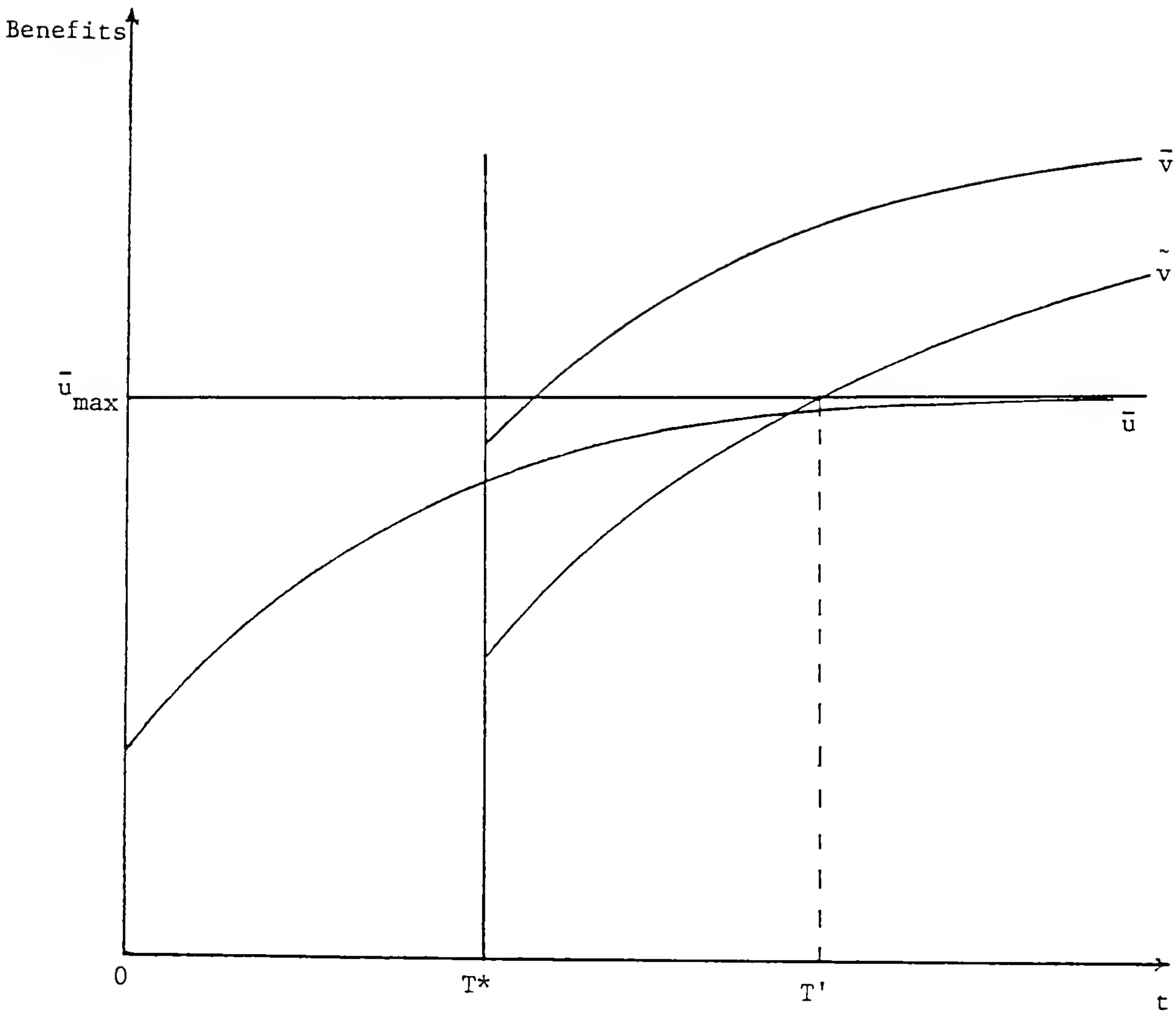

Figure 4: $\bar{u}(t)$ bounded from above

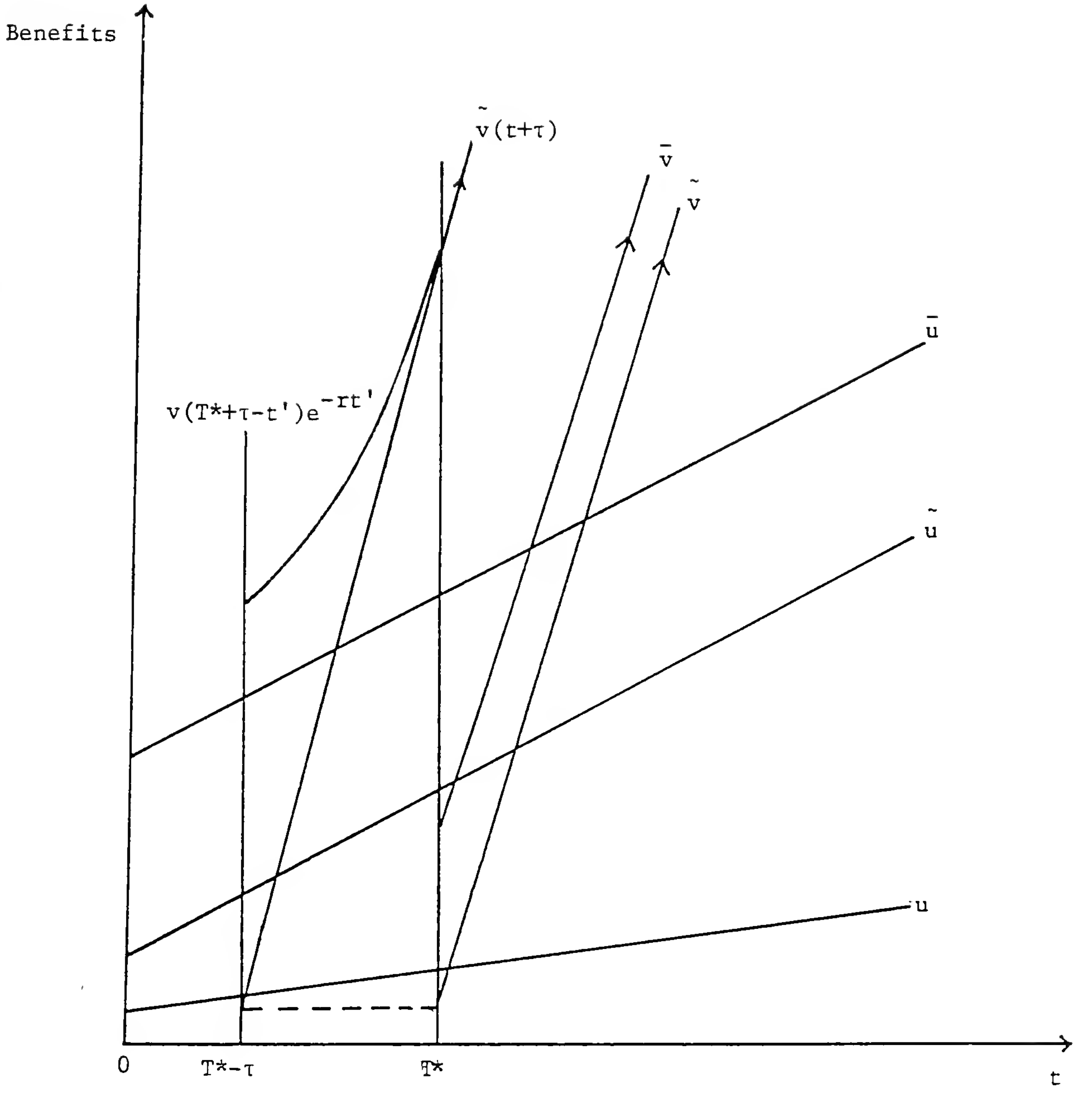

Figure 5: The Effect of a Preannouncement on Adoption

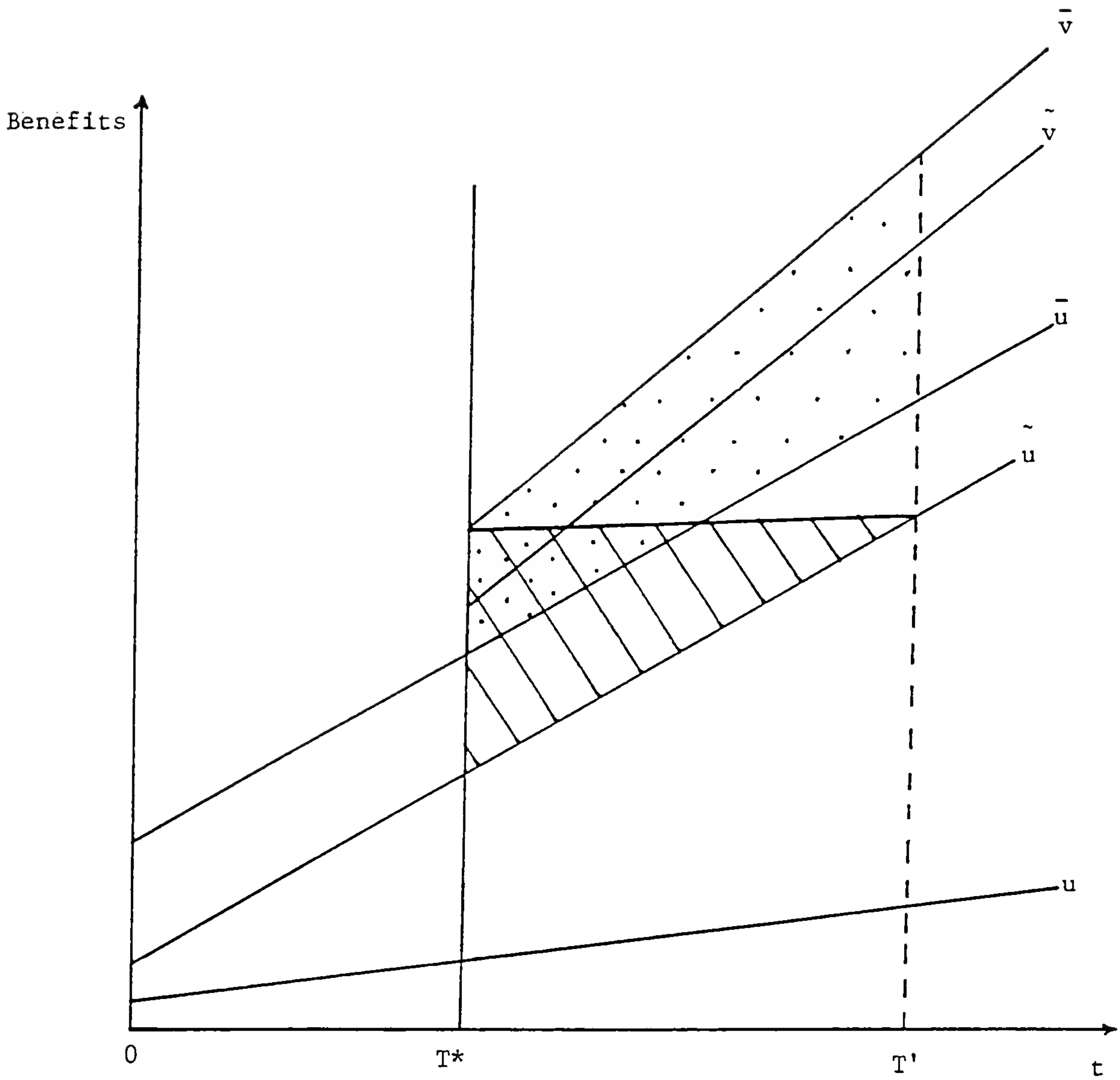

Figure 6: The Cost of Predation

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